EVALUATION OF REDUCTION OF PANTANAL WETLANDS IN 2012

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Abstract

The Pantanal wetland is liable to inter and intra-annual variations in flood pulses that can lead to socio-economic and environmental consequences, hence improved monitoring of this variability can provide opportunities for prediction of and adaptation to its impacts. Satellite images from TRMM and Terra/Aqua (MODIS sensor) allow the monitoring of rainfall and wetland inundation, respectively. The year 2012 showed the greatest reduction in the Pantanal flooded area since 2000. Compared to the average flooded area in the period 2000 – 2011, there was a reduction of 75% of the flooded area in 2012. The reduced inundation in 2012 was largely due to the decrease of the accumulated rainfall in the rainy season. TRMM data showed a reduction of 19% of the cumulative rainfall in the rainy season of 2012, since 81% of incident precipitations in Pantanal occur in this season, therefore these features led to the lowest rainfall rate since 2000. Among all years, the rainfall in the rainy season explained 53% of the flood pulse variability in the area. The delay or decrease in the rate of rainfall after the dry season is essential in the definition of the increase or decrease in the Pantanal wetland in the subsequent year and this monitoring may provide warning signs to predict extreme events in the flood pulse, since there is a considerable time lag between rainfall and inundation in many areas of the region.

Key-words: Floodplains. Wetlands. Precipitation. Flood pulses. Satellite images. Pantanal.

Resumo

Avaliação da redução das áreas alagadas no Pantanal em 2012

A planície do Pantanal é sujeita a pulsos de inundação inter e intra-anual com amplitudes que ocasionam consequências socioeconômico e ambiental, cujo monitoramento possibilitaria a intervenção humana para a amenização destes aspectos. As imagens dos satélites TRMM e Terra e Aqua (sensor MODIS) permitem o acompanhamento do regime pluviométrico e das áreas alagadas, respectivamente. Em 2012 ocorreu a maior redução de áreas alagadas no Pantanal desde 2000, ocasionada em grande parte pela combinação de condições naturais particularmente adversas. Observou-se a redução de 75% da área alagada em 2012 em relação a área média alagada de 2000 a 2011.Um dos fatores foi à diminuição de 19% da precipitação acumulada na estação chuvosa, visto que 81% da precipitação incidente na planície do Pantanal ocorrem nesta estação, portanto estas características ocasionaram o menor índice pluviométrico desde 2000. A precipitação incidente na estação chuvosa explicou 53% do pulso de inundação do Pantanal. O atraso ou diminuição da taxa de precipitação após a estação seca é parte essencial na definição do aumento ou da diminuição da área alagada do Pantanal no ano subsequente e este acompanhamento pode contribuir como um dos sinais de alerta a previsão de eventos extremos no pulso de inundação deste bioma.

Palavras-chave: Planícies fluviais. Áreas alagadas. Precipitação. Pulsos de inundação. Imagens de satélite. Pantanal.

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INTRODUCTION

The largest continuous plain subject to periodic intra and inter-annual flooding of the Earth in the tropical region is Pantanal. This Biome is located in Paraguay Upper River Basin - BAP (ABDON, 2004). It is composed of many ecosystems and presents one of the highest biodiversity in the world, both in animal and plant species, a determining factor for the 1988 Constitution to consider Pantanal as a national patrimony and for the United Nations Organization for Educational, Scientific and Cultural (UNESCO) in 2000 to include Pantanal as a World Patrimony and Biosphere Reserve.

The flooding regime is mainly dependent on its topography, an extensive plain with small slope, as well as on the intensity and distribution of rainfall in the BAP, which is characterized by a seasonal cycle that presents a rainy season from October to March and a dry season from April to September. This dynamic flooding is a key factor in determining the major biotic and abiotic processes, and, therefore, in the specific compositions of landscape units. The flooding dynamics presents a strong influence on agricultural activities, especially related to cattle management, which require the removal of the cattle to not flooded regions throughout the year.

The year 2012 was considered atypical in all Pantanal plain, verified by the reduction of water level in many rivers. The centennial rule of Ladário, MS, showed that since November 2011 the Paraguay River level was below the monthly level average, reaching in June 1.88 meters, while at the same date of 2011 the record reached 4.58 meters. This record type allows monitoring the floods or the droughts of Pantanal, serving as a warning to problems in both situations, however these data are not obtained for all the plain due to the large number of rivers and tributaries in the region.

The use of satellite images allows the estimation of the areas affected by flood pulses throughout its territorial extension. This estimate is possible due to the modification of natural elements by surface flooding, which causes significant changes in physical, chemical and biological interactions of these elements with electromagnetic radiation and, therefore, can be identified through images (PEREIRA et al ., 2007; ADAMI et al., 2008, SANTOS et al., 2009). An example is the MODIS sensor (Moderate Resolution Imaging Spectroradiometer) aboard Terra platform, whose temporal, spatial and spectral features combined with georeferencing quality of their products allows the discrimination and uninterrupted monitoring of flooded areas with good accuracy (MORAES et al., 2009; CARDOZO et al., 2010). The rainfall regime can also be monitored by TRMM satellite (Tropical Rainfall Measuring Mission), obtaining information about the atmosphere every three hours. Their estimates have been validated for different parts of the planet, including the Pantanal biome by Viana and Alvalá (2011).

OBJECTIVE

The objective of this work is to study and evaluate, through the use of images of MODIS sensor and TRMM Satellite, the reduction of Pantanal wetlands during the wet season for the year 2012 as opposed to the period from 2000 to 2011.

MATERIALS AND METHODS

The study area is represented by the Pantanal region and the origin of major rivers (in the Brazilian plateau), combined with the great extent of the plain, 138,183 km^2 and small slope (average altitude ranges from 60 to 150 m), originating the occurrence of a complex flooding system. This plain is primarily composed of tributaries on the left border of Paraguay River in Brazil, with its western edge touching the territory of Bolivia to the north and Paraguay to the south. Pantanal covers parts of the Mato Grosso do Sul (65%) and Mato Grosso (35%) States, presenting a climate with annual average temperature of 25º C, with a minimum of 15º C and a maximum of 34° C.

According to Viana and Alvala (2011) the average annual rainfall of the last 14 years was approximately 1220 mm, ranging from 239 mm in the dry season (April to September) to 1002 mm in the rainy season (October to March), while the annual average in BAP is 1400 mm, ranging from 800 to 1600 mm, evidencing that the greatest pluviometric rates are observed in the plateau (ANA/GEF/PNUMA/OAS, 2004).

In this work we used images of MODIS sensor, represented by MOD43B3 product and 3B43 product of TRMM Satellite. Both products have been extensively validated for different regions of the globe. The MODIS products represent the albedo, the photosynthetically active reflectance (PAR) and the near and mid infrared (NIR/SWIR) data representative of each 16 days with a spatial resolution of 1 km. The images are represented by H12V10 and H12V11 tiles and cover the Pantanal area.

The analyzed period includes images from February 2000 to September 2012. All these images have been redesigned and treated based on pixel reliability, in order to exclude the elements contaminated with clouds, aerosols and shadows. Moreover, in this work we eliminated pixels with sensor inclination more than 30º relating to vertical target. Thus the final product generated every 16 days represents the more representative pixels of albedo or reflectance (PAR and NIR/SWIR) of surface. The methodology of Cardozo et al. (2010) was adopted for the wetland delimitation.

The 3B43 TRMM products represent monthly average precipitation maps originated from a monthly round of 3B42 algorithm subproducts, which combine precipitation estimates of microwave bands obtained by SSM/I (Special Sensor Microwave Imager), AMSU-B (Advanced Microwave Sounding Unit-B) and AMSR-E (Advanced Microwave Scanning Radiometer-E) sensors to adjust the precipitation estimates in the infrared band every 3 hours. Through monthly precipitation maps, which have a spatial resolution of 0.25° of latitude and longitude, were obtained. The monthly rainfall average for BAP was obtained for all months from October 1999 to August 2012, and for this study the monthly rainfall average was determined for the Pantanal.

RESULTS AND DISCUSSIONS

The monthly precipitation maps derived from TRMM enabled to evaluate the precipitation dynamics of the Pantanal Biome for the past 13 hidrologic years (October 1999 to August 2012). The monthly climatology of incident rainfall in the region and the representation of its behavior by a graphic diagram box (box-plot) are shown in figure 1. The median distribution showed that the monthly precipitation variability meets the expectations, that is, greater variability in the rainy season and lower variation during the dry season.

It was also possible to identify the months with unusual values (outliers) superior to the other indices of their occurrence months, such as the extreme values which occurred in the months of May and June 2012, whose rainfall values were, respectively, 119% and 321% above the monthly average obtained for these thirteen years. The other outliers occurred in July 2000 and 2009 and in October 2004, with precipitation rates 199%, 151% and 46.6% higher than their respective averages. It was also verified that the years with higher and lower rates of precipitation in Pantanal were 2011 and 2012.

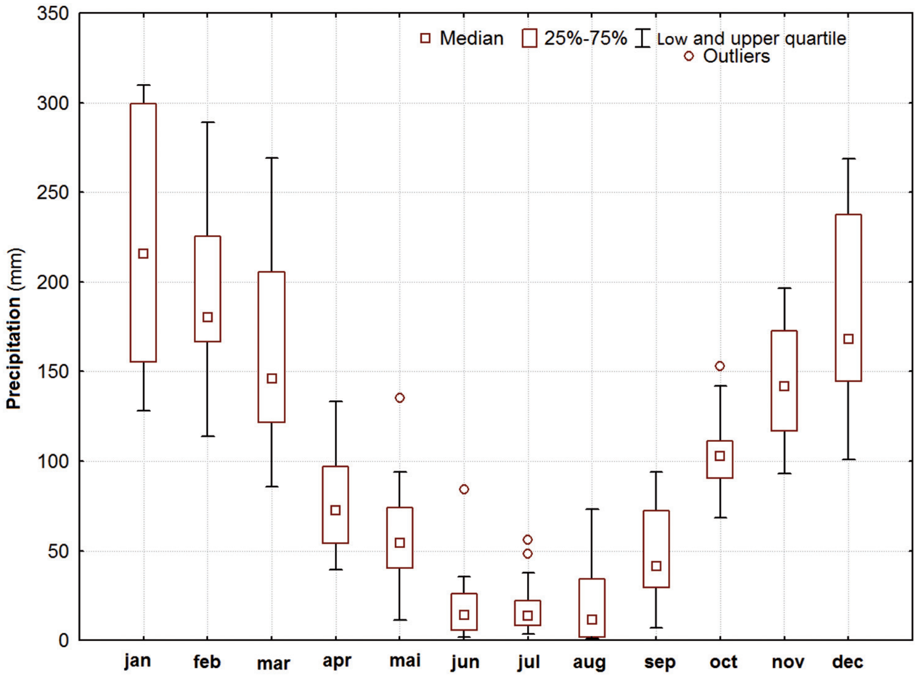

Figure 1 – Diagram box of monthly rainfall in Pantanal biome from January 2000 to August 2012 period

Figure 2 show that 2012 presented the lowest rainfall level in this period. The annual average accumulated precipitation for the rainy and dry seasons of Pantanal (Figure 2a) shows that in the last 13 years 81.2% of the annual rainfall in the region occurs in the rainy season, which covers the months from October to March. The average cumulative rainfall in this season for the period from 2000 to 2011 was 1016 mm, while the average for this season in 2012 was 823 mm, presenting a decrease in precipitation of 19%. This year contrasts with the previous hydrological year (October 2010 to September 2011), which presented the highest rainfall level among the rainy seasons, with a superior percentage of 17% for the period.

The average monthly rainfall distribution from 2000 to August 2012 and monthly values of precipitation for the years 2011 and 2012 for Pantanal shown in figure 2b allow observing that the rainy season of 2011 showed the highest rate of precipitation of the last 13 years, or, 15.4% higher than the average rainfall for the season, which represents 183 mm of precipitation, however, it is observed that for the first three months of 2011 the rainfall was higher than the rainy season average (50.4% or 279 mm in the quarter). It is noteworthy that the first quarter of 2011 hydrological year, composed of the first three months of the rainy season (October to December 2010), showed a deficit of -19.7% compared to the average precipitation for the period. However, the 2012 rainy season proved to be drier than the average of this season, suffering a reduction in rainfall of 17% (183 mm). There was a reduction of 16% in precipitation in the first three months of this hydrological year (October, November and December 2011) and a reduction of 18% in the three subsequent months that compose this season (January, February and March 2012).

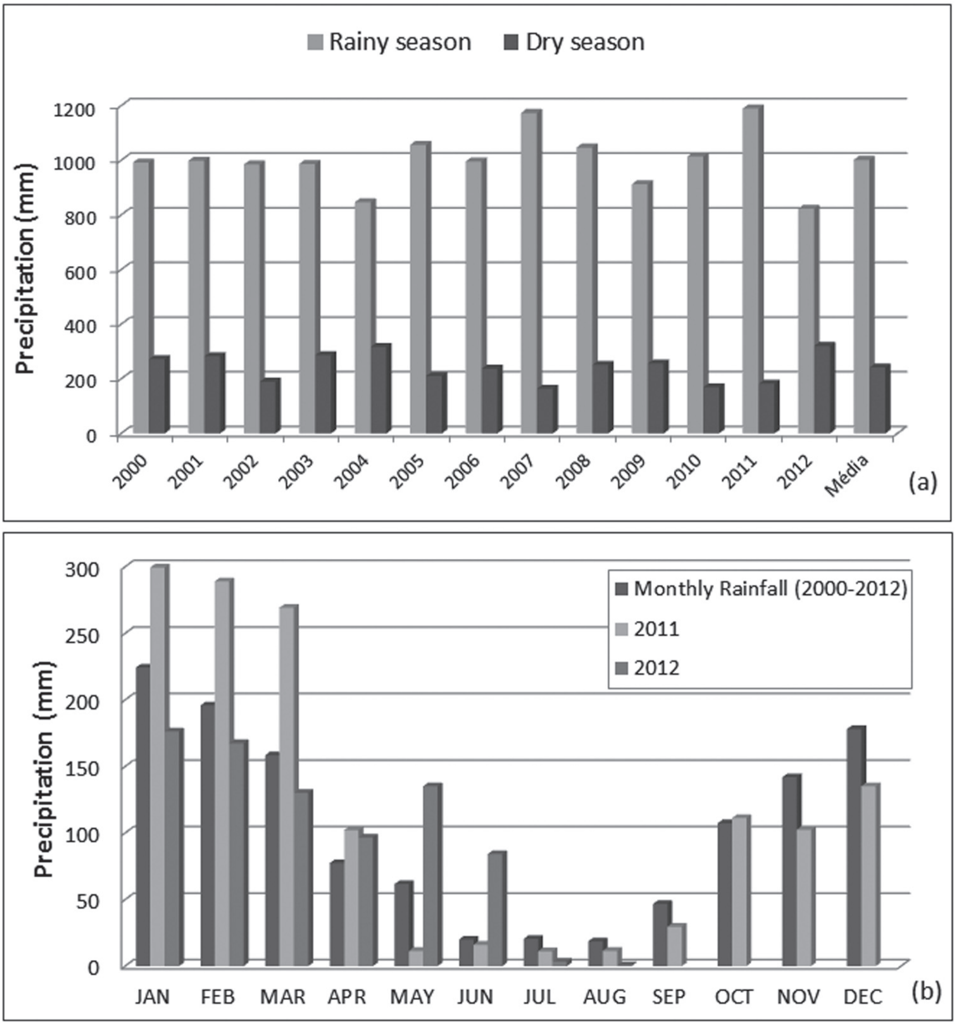

Figure 2 - Annual average of cumulative rainfall for the rainy and dry season in Pantanal from 2000 to August 2012 period (a) and average monthly rainfall incident on the plain (b)

With the exception of October 2011, which showed a slight increase (3.6%) of the average monthly rainfall, all other months of 2012 wet season presented a decrease in intensity, whose variations ranged from 27.8% in November 2011 to 14.5% in February 2012. The dry period preceding the rainy season of 2012 showed a severe drought, with a reduction of 31.7% of rainfall or 63 mm related to the average of this season in the last 13 years while only the dry season of 2007 showed a higher drought index.

The monthly rainfall indices presented in Figure 2b show that after the severe drought in the rainy season of 2012 hydrological year there was an increase in precipitation levels in the months of April, May and June (25, 119 and 321%, respectively, which correspond to 19, 73 and 64 mm of rainfall). However, the precipitation was not homogeneous in the biome, as can be noted in Figure 3, which spatializes the monthly rainfall average in May and June of 2012.

It is verified that there were positive deviations related to the average of the last 13 years for the entire Pantanal, with the highest levels of rainfall for the month of May, higher than 90 mm compared with the climatological average, which occurred almost throughout the Pantanal belonging to Mato Grosso State and the northern Pantanal of Mato Grosso do Sul. For June the higher precipitation levels, with deviations greater than 60 mm of the average, occurred in the east region of the Pantanal located in Mato Grosso and in the north, east, and south regions of the Pantanal located in Mato Grosso do Sul. However, since July the Pantanal Biome has again been facing a strong drought with a reduced precipitation around 90% of the climatological average, a percentage that is less than 35 mm of the average precipitation for July and August months.

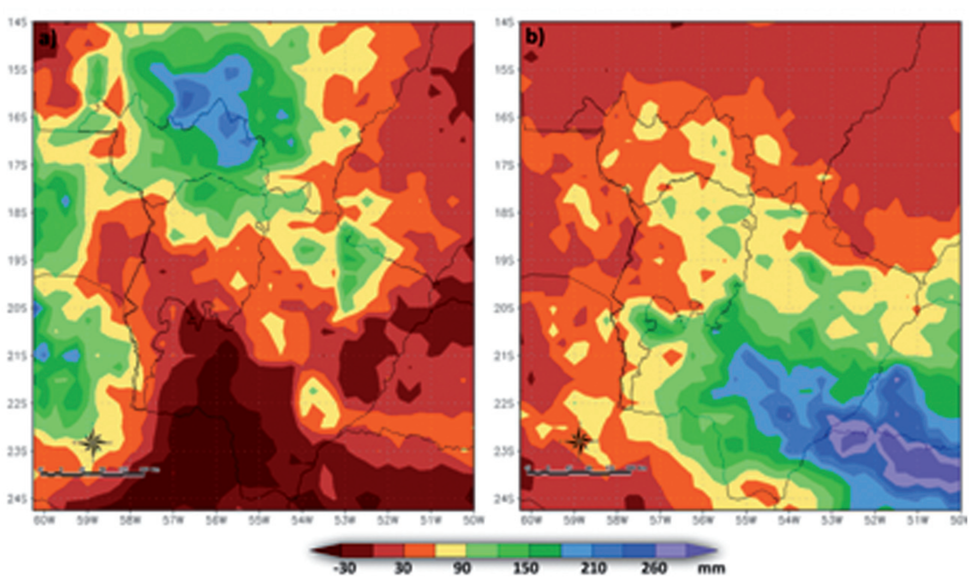

Figure 3 - Stratification of 2012 average monthly rainfall deviations compared to the monthly average of 2000 to 2012 period for May (a) and June (b) months

In figure 4 the incident average rainfall in the region is spatialized to the wet and dry seasons for both the 13 year period and the year of 2012. It was noticed that for 2012 the precipitation rates were low compared to the average in the wet season for almost all the Pantanal biome, except for the northeast and south of the biome, while for the dry season the rainfall presented levels above average for almost all the region, with rates higher than 80 mm in the south and northeast of the biome. In 2012 rainy season the rainfall in the north and northeast plateau showed values equivalent to those of the climatological average of the rainy season.

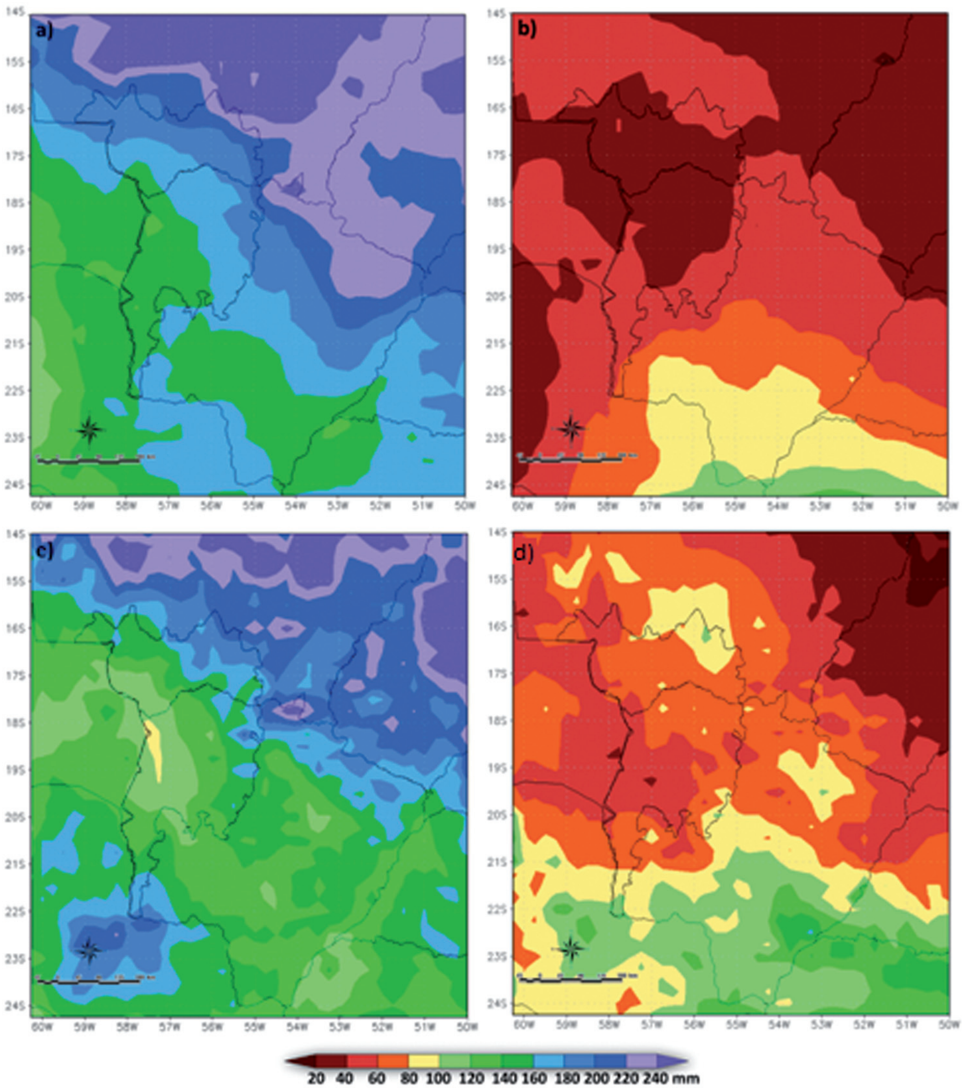

Figure 4 - Precipitation maps for wet and dry seasons. Average of 2000 to 2012 hydrological years for wet season (a) and dry season (b); and average of 2012 hydrological year for wet season (c) and dry season (d)

The spatial distribution of Pantanal wetlands can be seen in figure 5, which presents the annual monitoring of wetlands for 2000-2012 hydrological years, which allows analyzing the interannual flood pulse for Pantanal in the past 13 years, identifying the maximum spatial extent of the pulse.

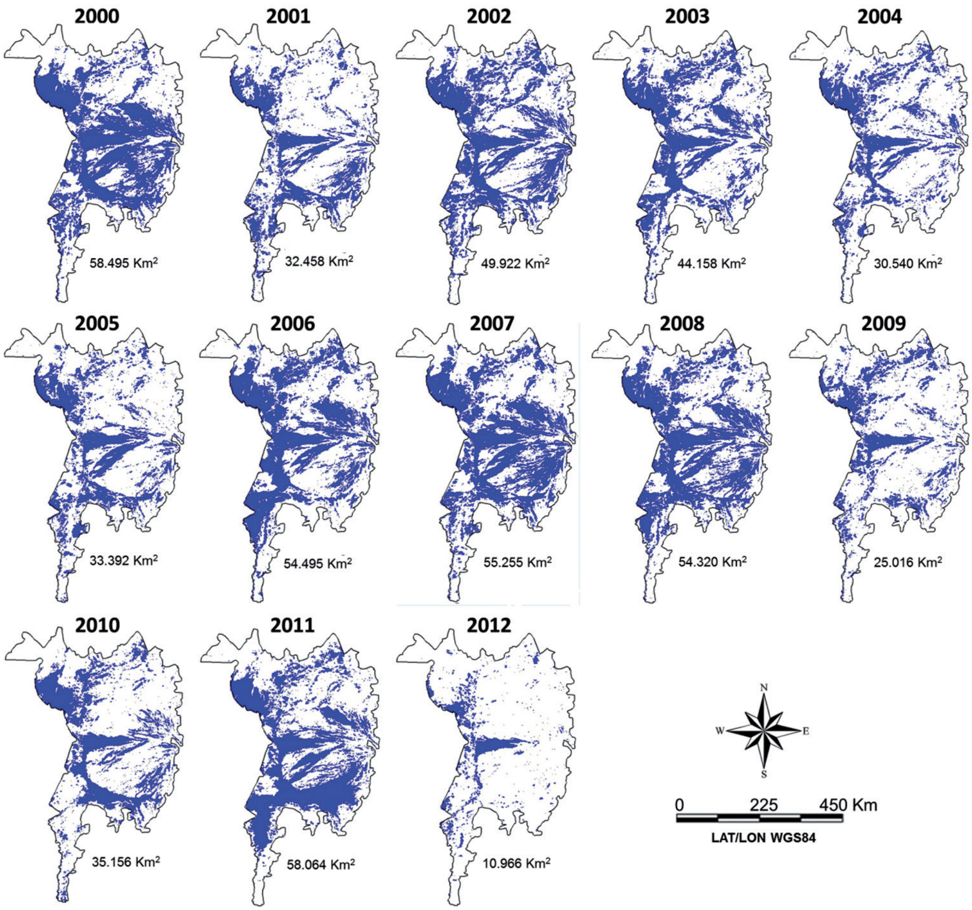

Figure 5 - Annual maps of prone flooding areas in Pantanal of 2000 to 2012 hydrological years

Along these years it was observed that 2012 hydrological year presented the lowest flooded area, whereas in the previous decade the year that presented the smallest flooded area was 2009. In the 2009 hydrological year the flooded area in the plain was 25,016 km², while in 2012 the flooded area totaled 10,966 Km². These wetlands account for 18.1% and 7.94% of the total Pantanal area, respectively.

From 2000 to 2011 the average flooded area in the plain was 31.8%, which represents 43,978 Km² of flooded area, therefore, in 2012 a reduction of 75.1% occurred in the average flooded area of the previous twelve years. It is noteworthy that the years that presented the greatest extent of flooded area were 2000 and 2011, with a percentage of 42.3% and 42% compared to the total area of Pantanal, respectively. Figure 6 shows the quarterly wetlands of Pantanal in 2012, where a small extension of wetlands for this year, which in general are permanently flooded, can be observed.

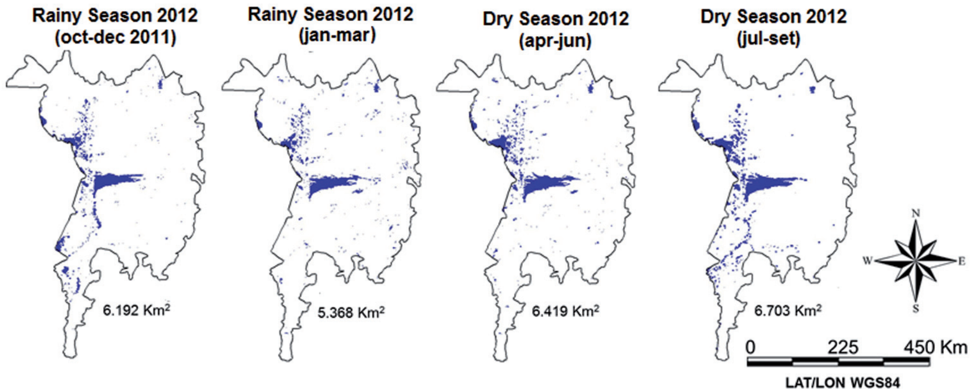

Figure 6 - Quarterly maps of Pantanal wetlands for 2012 hydrologic year

Figure 7 shows the values of wetlands in the Pantanal biome for 2000-2012 hydrological years and the average accumulated annual precipitation for the rainy season (gray line) and for the hydrological year (blue line) in this period. From the analysis of figures 2, 5 and 7 a certain periodicity in the Pantanal flood pulse can be observed and the incident rainfall in the wet season explained 53% of the pulse, since the correlation between the cumulative rainfall in the rainy season and wetlands in 2000 to 2012 period presented a coefficient of 0.73, while the correlation with the accumulated rainfall in hydrological year was 0.69. It was observed that the periodicity of the flood pulse coverage is directly related to the rate of annual incident rainfall in the drainage basin, as well as to the behavior of the dry season and the rainfall in this region, however, these factors do not fully explain the expansion or reduction of flooded area.

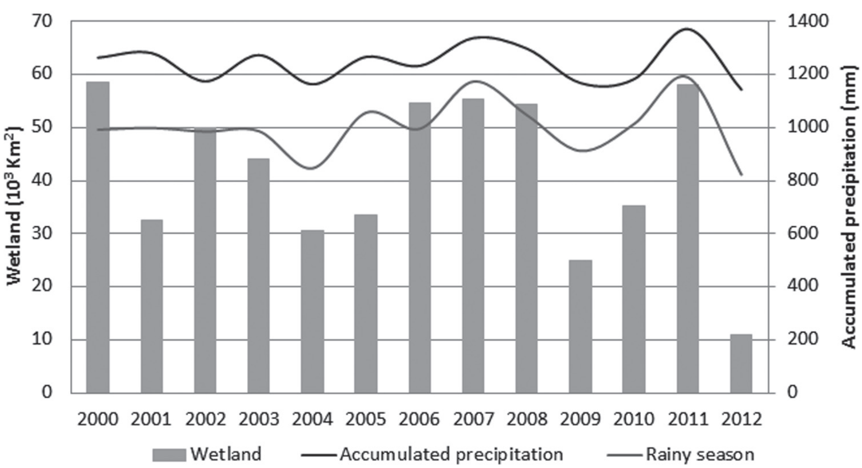

Figure 7 – Wetlands and accumulated precipitation annual averages in the rainy season and for 2000 to 2012 hydrological years

From the analysis of the monthly precipitation average it was observed that there is a temporal lag between the precipitation regime of Pantanal and the evolution of wetlands, resulting in average to two to three months of lag.

The spatial distribution of precipitation rates, obtained from TRMM, enables the identification of areas that could suffer greater impacts due to stress caused by the rains. Figure 8 illustrates the distribution of accumulated rainfall in the plains for the dry and rainy seasons of 2009 and 2012.

Although 2009 and 2012 rainy seasons (Figure 8a and 8d) presented the lowest precipitation rates since 2000 in Pantanal, the dry season (Figure 8h) that preceded 2012 hydrological year showed the lowest precipitation values (accumulated rainfall average between 100 and 200 mm) for all the plain when compared to 2009 dry season (accumulated rainfall average between 200 and 300 mm), except for the southern Pantanal.

It is noteworthy that the great extent of 2011 flooded area is consistent with the fact that 2011 hydrological year presented the highest rainfall rates since 2000 in the plain, even preceded by a dry season with lower rainfall rates compared to the dry season prior to 2012.

Figures 6 and 8 show that the first quarter of the rainy period of 2012 hydrological year already showed a small flooded area (Figure 6a), and this fact was influenced by a severe drought in the early period of the dry season, not only in the Pantanal plain but also in the plateau as evidenced in figure 8h. In this quarter there was a reduction of 78 mm in precipitation related to the past 12 hydrological years. This drought persisted throughout the subsequent quarter (January to March 2012) causing a reduction of 19.1% in precipitation related to the average of 2000-2011, resulting in a lower extent of flooded area in this year, or, 5,368 km^2, as it can be seen in Figure 6b.

The beginning of precipitations occurred in April 2012 persisted until June, with deviations greater than the monthly rainfall average for 2000 to 2011 years of 27.7%, 143.5% and 474.9%, representing respectively 21, 80 and 70 mm of rainfall above the monthly average of these years. This fact caused an increase in the flooded area for this quarter (1,051 km^2), considered as the beginning of the dry season, influencing the flooded area increase in the subsequent quarter (284 km^2) even with the severe drought occurred in this period, providing a reduction of 90.4% in rainfall compared to pluviometric average of July and August for the past 12 years. It is interesting to point out that most of the wetlands which occurred in 2012 hydrologic year are generally areas that are permanently flooded.

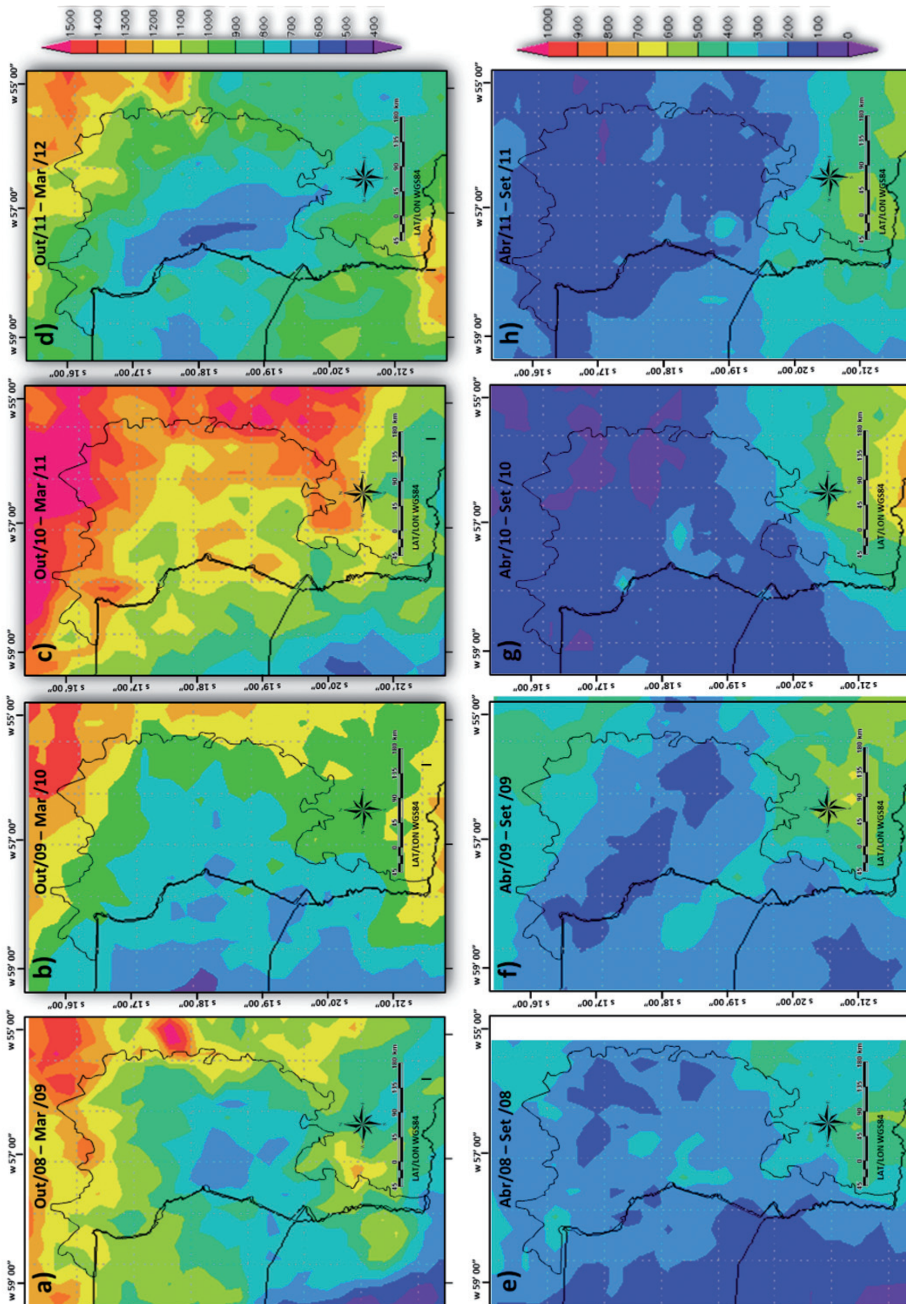

Figure 8 - Accumulated precipitation maps in Pantanal for wet season (a, b, c, d) and dry season (e, f, g, h) of 2009 to 2012 hydrological years

Meteorological satellite images indicate that the total Pantanal wetlands are influenced by waters from the northern region of the country, since the precipitation regime of Pantanal is not the only factor that causes the flooding in this biome. The number of events related to the flooding of all analyzed years is shown in figure 9a, while figure 9b shows the comparison between 2012 wetlands (blue) and flood areas whose frequency presents values above the average occurrence of floods in 2000 to 2011 period (red).

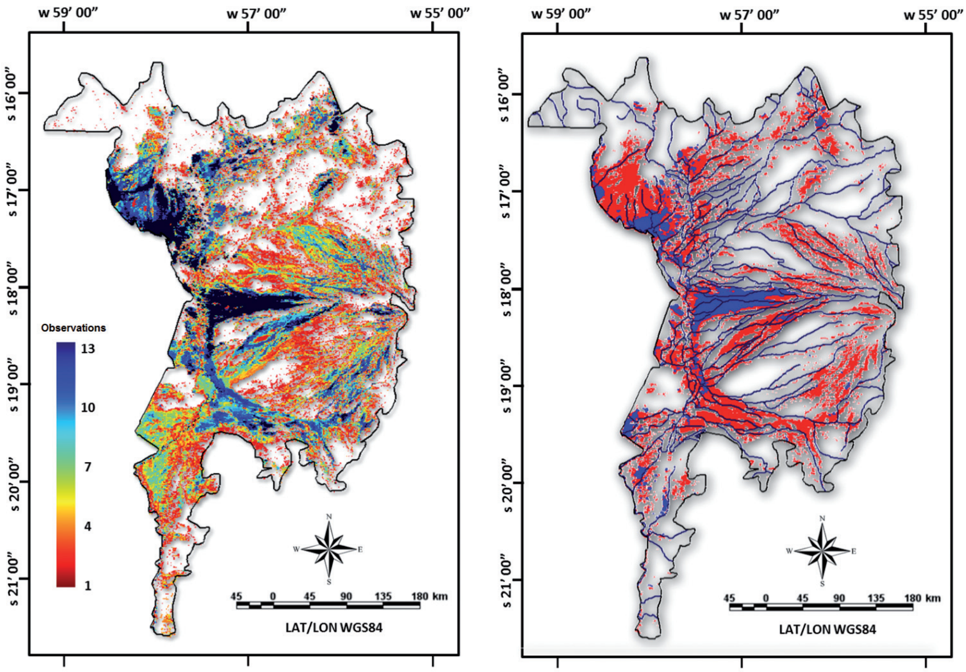

Figure 9 - **Map of the number of events related to flooding during the period 2000 to June 2012 (a) and comparative map of wetlands in 2012 (in blue) with regions whose frequencies of flood events were superior than 6 years (red)**

The darkest areas in figure 9a show the permanently flooded areas in Pantanal, while areas in red define the regions which were rarely flooded, even in years that the rainfall of BAP was high. Permanently flooded areas are mainly strongly influenced by the Paraguay River, central part of the Taquari fan and northwest of the Pantanal biome. Figure 9b highlights the reduction of flood pulse of the 2012 hydrologic year compared to the entire study period.

It is verified that the higher fraction of flooded area belongs to permanently flooded regions. However, in general this flooded area in 2012 is located in the west and northwest of the plain. The precipitation maps shown in figures 8d and 8h explain part of the flooding in the southwestern region of Pantanal, since in the 2012 hydrological year this region presented the highest rate of rainfall during the dry season (Figure 8h), as well as consistent indices compared to the higher rates observed in the northern and eastern plains during the rainy season in this year.

The satellite images allow the monitoring of precipitation regime and flood pulse of the Pantanal biome, which presents great inter and intra-annual variability. In 2012 a strong reduction in the extent of flooding in Pantanal was observed, and compared to 2000-2011 period the value was 75.1% of the average flooded area in the last 12 years. One of the factors that led to this decrease was the reduction of 19% of the rainfall in the rainy season, the lowest rainfall rate since 2000. Although the first quarter precipitation of the dry season was 170 mm higher than the average of the last 12 years, this fact was not enough to mitigate the environmental and socioeconomic problems in the region caused by the drought in the rainy season, whereas July and August showed a reduction in rainfall of 90%.

The reduction or delay of precipitation in Pantanal after the dry season is essential to define the flooded area in the following year therefore the monitoring of rainfall rates can contribute as warning signs for predicting drought or flooding years in Pantanal. The detailed study of precipitation regime in BAP will enable a better understanding of this flood dynamics, since over these 13 years wetlands were not proportional to the amount of accumulated rainfall in the plains, whereas for the studied period the incident rainfall in the rainy season explained 53% of the average area of the Pantanal flood pulse and, therefore, this pulse is also influenced by the precipitation regime in the plateau, a region that originates the majority of the rivers of the basin.

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